

Using an Online Games-Based Learning Approach to Teach Database Design Concepts

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Abstract: The study of database systems is typically core in undergraduate and postgraduate programmes related to computer science and information systems. However, one component of this curriculum that many learners have difficulty with is database analysis and design, an area that is critical to the development of modern information systems. This paper proposes a set of principles for the design of a games-based learning environment to help the learner develop the skills necessary to understand and perform database analysis and design effectively. The paper also presents some preliminary results on the use of this environment.

Keywords: Collaborative e-learning; innovative teaching and learning technologies for web-based education; e-pedagogy; design and development of online courseware.

1. Introduction

The database is now the underlying framework of the information system and has fundamentally changed the way many organizations and individuals work. This is reflected within tertiary education where databases form a core area of study in undergraduate and postgraduate programmes related to computer science and information systems, and typically at least an elective on other data-intensive programmes (ACM/IEEE, 2001; EUCIP, 2003). The core studies are commonly based on the relational data model, SQL (the *de facto* language for relational DBMSs), data modelling and relational database design. This curriculum supports industry needs where the relational DBMS is the dominant data-processing software currently in use, with estimated new licence sales of between US\$6 billion and US\$10 billion per year (Connolly and Begg, 2004).

With more than 30 years since Codd proposed the relational data model in his seminal paper, the core relational theory is a mature and established area in relation to other parts of the computing curriculum. However, one component of this curriculum that many learners have difficulty with is database analysis and design. For the purposes of this paper we use the term 'database analysis and design' to encompass requirements analysis, conceptual database design (including ER modelling), logical database design (including mapping to the relational model and validating the model using normalization) and physical database design (Connolly and Begg, 2004).

In this paper, we explore a range of teaching techniques that supplement traditional teaching methods with more non-traditional methods based on interactive visualization and computer games to help overcome these difficulties and help the learner develop the skills necessary to understand

and perform database analysis and design effectively.

1.1 Problems with teaching database analysis and design

Mohtashami and Scher (2000) note that pedagogical strategies for teaching database analysis and design traditionally follow a similar modality to that of other technical programmes in computing science or information systems. A significant amount of technical knowledge must be imparted with the lecturer becoming a 'sage on stage' and the students passive listeners. While students tend to cope well with basic concepts and practical components of the curriculum, one area that many students find difficult is the abstract and complex domain of database analysis and design. A comparable problem has been identified with object-oriented analysis and design, which is also highly abstract (e.g. Yazici et al., 2001). This is borne out by a recent European survey that found that the primary skill that organizations considered to be lacking in both new IT graduate recruits and current IT staff was database design (database tuning and database administration were second and third, respectively) (Connolly and Laiho, 2004).

To undertake database analysis and design effectively for an even moderately complex system, a student requires (among others) the skills to:

- work in a project team and apply appropriate fact-finding techniques to elicit requirements from the client (both 'soft', people-oriented skills);
- conceptualise a design from a set of requirements ('soft', analytical skills),
- map a conceptual design to a logical/physical design ('hard', technical skills);

- reflect and review intermediate designs, particularly where information complexity is present (a combination of 'soft' and 'hard' skills).

Students often have considerable difficulty comprehending implementation-independent issues and analysing problems where there is no single, simple, well-known or correct solution. They have difficulty handling the ambiguity and vagueness that can arise during database analysis. Students can also display an inability to translate classroom examples to other domains with analogous scenarios, betraying a lack of analytical problem-solving skills. For the students these problems can lead to confusion, a lack of self-confidence and a lack of motivation to continue.

In this paper we explore the use of interactive visualization and computer games to provide a web-based collaborative learning environment to supplement traditional methods of teaching database analysis and design. We have chosen to examine such an environment for several reasons:

- The younger generation have grown up in a technologically sophisticated environment populated by home computers, the Internet, graphic-rich movies, multi-player Internet gaming, Nintendo GameBoys™, XBoxes™, DVD players, mobile phones, interactive television and iPods™, which has led to changes in their experiences, attitudes and expectations (e.g. Prensky, 2001; Kolb et al., 2001). This suggests that we should investigate and exploit those aspects of the technologies the modern learner has been exposed to, such as computer games, with a view to identifying those aspects that might be transferable *in pedagogical terms*, into teaching (Connolly et al., 2004).
- There is empirical evidence that games can be an effective tool for enhancing learning and understanding of complex subject matter (Ricci et al., 1996; Cordova and Lepper, 1996).
- Educationalists are interested in the intensity of involvement between instructional strategies, motivational processes and learning outcomes. It would be highly desirable to harness the appropriate properties of computer games that enhance learning and improve student performance.

This paper is structured into four further sections. The next section discusses the pedagogical basis for developing a problem-based learning environment based on visualization and computer games to teach database analysis and design, leading in the section thereafter to a set of principles for the design of the proposed learning environment. The penultimate section discusses the on-going design of this environment. The final section pro-

vides some concluding remarks and directions for future research.

2. Previous Research

In this section we examine previous research related to the use of computer games in education, covering motivation and flow; constructivism as a pedagogical approach to learning and the appropriateness of problem-based learning for our purposes.

2.1 Motivation

Motivation is a key concept in many theories of learning. Katzeff (2000) stresses motivation is a critical factor for instructional design and for learning to occur the learner must be motivated to learn. Malone and Lepper (1987) present a theoretical framework of intrinsic motivation in the design of educational computer games. They postulate that intrinsic motivation is created by four individual factors: challenge, fantasy, curiosity and control and three interpersonal factors: cooperation, competition and recognition. Interestingly many of these factors also describe what makes a good game, irrespective of its educational qualities.

Prensky (2001) defines the key characteristics of (simulation) games as: rules, goals and objectives, outcomes and feedback, conflict (and/or competition, challenge, opposition), interaction, and representation of story. While intrinsic motivation is highly desirable, many of the activities in which learners engage in is directly influenced by extrinsic rather than intrinsic motivation (Csikszentmihalyi and Nakamura (1989). Unfortunately evidence suggests that extrinsic motivators may lead to merely short-range activity while actually reducing long-range interest in a topic while with intrinsic motivators learners tend to persist longer, work harder, actively apply strategies and retain key information more consistently. Thus, extrinsic motivators must be supported by intrinsic motivators, otherwise the result is likely to be a reduction in the very behaviour we want to promote. One of the most serious problems that research has pointed out during the past two decades is that extrinsic motivation when used alone is likely to have precisely the opposite impact that we want it to have on learner achievement (Lepper and Hodell, 1989).

In determining what makes a particular situation or activity intrinsically motivating to an individual, the Csikszentmihalyi's (1990) concept of *flow* is often mentioned. The conditions likely to induce the state of flow are challenge, control, performance criteria and feedback (Connolly et al., 2004).

2.2 Constructivism and learning environments

2.2.1 Constructivist and sociocultural theory

While traditional education was guided by the paradigm of didactic instruction there is now an emphasis on *constructivism* as a philosophical, epistemological and pedagogical approach. Constructivism focuses on knowledge construction, not knowledge reproduction (Collins, 1991). Vygotsky's *sociocultural theory* of learning emphasises that human intelligence originates in our culture. Individual cognitive gain occurs first in interaction with other people and in the next phase within the individual (Forman and McPhail, 1993).

According to Gance (2002) the main pedagogical components commonly associated with these models are:

- A cognitively engaged learner who actively seeks to explore her environment for new information.
- A pedagogy that often includes a hands-on, dialogic interaction with the learning environment. For example, actually designing a database is preferred to simply being told how to design a database.
- A pedagogy that often requires a learning context that creates a problem-solving situation that is realistic.
- An environment that typically includes a social component often interpreted as interaction with other learners and with mentors in the context of learning.

2.2.2 Problem-based learning

Many researchers have expressed their hope that constructivism will lead to better educational software and better learning (e.g. Brown et al., 1989; Jonassen, 1994). They emphasise the need for open-ended exploratory authentic learning environments in which learners can develop personally meaningful and transferable knowledge and understanding. The *problem-based learning (PBL)* model encompasses the principles of constructivism. With PBL the teacher (facilitator) is available for consultation and plays a significant role in modelling the metacognitive thinking associated with the problem-solving process. This reflects a *cognitive apprenticeship* environment (Collins et al., 1990) with *coaching* and *scaffolding* (e.g. offering hints, reminders and feedback) provided to support the learner in developing metacognitive skills. As these skills develop, the scaffolding is gradually removed. The intention is to force learners to assume as much of the task on their own,

as soon as possible. The cognitive apprenticeship model also advocates:

- *modelling*, which involves an expert (the teacher) performing a task so that the learner can observe and build a conceptual model of the processes required to accomplish it;
- *articulation* (either verbal as mentioned above or written);
- *reflection*, to enable learners "to compare their own problem-solving processes with those of an expert, another learner, and ultimately, an internal cognitive model of expertise" (Collins et al., 1990);
- *exploration*, to push learners into a mode of problem-solving on their own.

Savery and Duffy (1995) comment that PBL should stimulate, and therefore engage the learner in, the problem-solving behaviour that the practicing professional would employ. The PBL approach is now used across a range of subject disciplines.

A similar concept to articulation that has been cited as an important element of simulation games is *debriefing* (Lederman and Kato, 1995). Games and simulations differ in that simulations include elements of the real world whereas games are "separate from the real world". Debriefing is an essential element of any simulation game because it links what has been experienced during the simulation with learning. Debriefing provides the opportunity for learners to consolidate their experience and assess the value of the knowledge they have obtained in terms of its theoretical and practical application to situations that exist in reality.

3. Guiding Principles For The Online Games-Based Learning Environment

We illustrate the influences for the online games-based collaborative learning environment that we are developing to teach database analysis and design based on the above research in Figure 1, depicting the relationships between the game, the teacher, learners and the environment. In addition, we put forward our own principles for the learning environment as follows:

1. Start with an authentic problem grounded in professional practice. This problem should be both realistic and sufficiently complex to develop analytical and problem-solving skills.
2. Encourage learners to take responsibility (ownership) for learning and to be aware of the knowledge construction process.
3. Allow learners to develop their own process to reach a solution.

4. Provide learners with the opportunity to experience and appreciate other perspectives (this may come about as part of the next principle).
5. Provide opportunities for interaction and collaboration, either learner-learner, learner-teacher or learner-system.
6. Ensure that the learning environment motivates, engages and challenges the learner.
7. Provide feedback mechanisms to enable learners to be fully aware of their progress.
8. Provide support mechanisms for learners using coaching and scaffolding.
9. Be flexible to support different learning styles.
10. Provide opportunities for reflection, self-evaluation, articulation and debriefing.
11. Provide an integrated assessment.

While many examples of collaborative learning are in the more traditional face-to-face mode, there is evidence that supports the view that collaboration that is many-to-many, time and place independent, and distributed can have its advantages (e.g. Warschauer, 1997). As we discuss shortly, early results from a prototype of the learning environment that we have developed are encouraging and show enhanced performance across the student cohorts.

4. Designing the learning environment

Video case studies have been used for several years within computing-related undergraduate and postgraduate modules in the School of Computing at the University of Paisley. The videos were developed by the School to provide students with real-world organizational problem scenarios such as organizational change within a library, a marina and a veterinary practice through which they could develop and apply a range of different skills and concepts. Although the use of the videos was found to be engaging, their main drawback was that students could not interact with the characters and scenarios presented to them, they could only view them in a sequential, linear and passive fashion. In addition, for several years the School has been developing online learning materials for various undergraduate and postgraduate modules/programmes as well as interactive visualizations that enhance these materials. In particular, material has been developed for the undergraduate 'Introduction to Database Systems' and the postgraduate 'Fundamentals of Database Systems' modules.

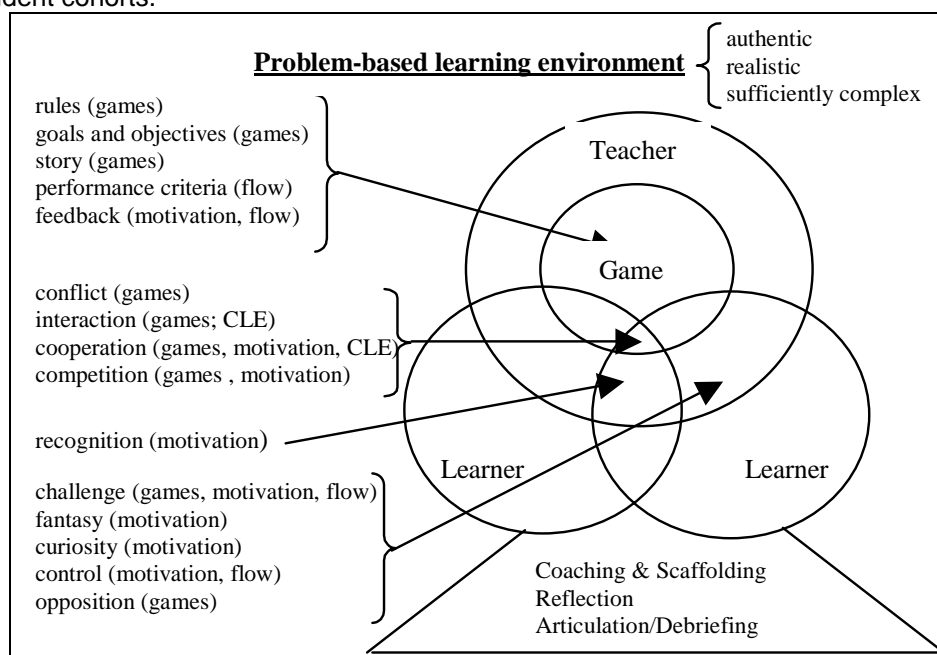


Figure 1: Influences for the online games-based learning environment

To develop the students' learning experience further in these two modules, it was decided to develop an educational simulation game around the video case studies and use the interactive visualizations and online learning materials as a form of *digital scaffolding* in an attempt to increase student interactivity and engagement with the prob-

lem scenarios being presented. For example, students would be able to interact with the characters by asking different types of preset questions, which would influence the outcome of the problem situation. The simulation game provides the opportunity for students to learn and apply a range of relevant skills and techniques relating to data-

base analysis and design within a more interactive, engaging and stimulating environment more akin to the real-world setting that students may find themselves in industry.

The simulation game is part of a wider learning environment as shown in Figure 2. The following three main components form the learning environment:

- The online learning units/topics (entry level 1) introduce the concepts to be explored; these units are structured in a hierarchical manner allowing students to 'drill down' to obtain further details. Topics are hyperlinked to allow non-sequential browsing.
- The visualizations (entry level 2) enhance learning by providing animated walkthroughs of specific examples (e.g. construction of an ER diagram or the process of normalization).
- The simulation game (entry level 3) provides a real-world simulated environment within which to apply skills and techniques.

The simulation game is part of a natural evolution of the learning environment in which all three elements work together. This means that students working through the simulation game can pause at appropriate points and 'drill down' via the Digital Assistant to the interactive visualizations or to individual topics.

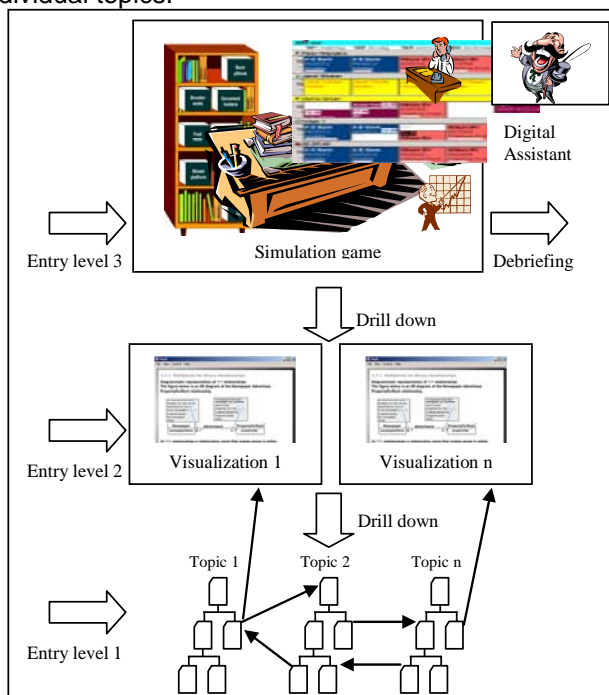


Figure 2: The learning environment.

5. Preliminary results

At present, levels 1 and 2 of the environment have been developed and initial findings are positive. We have three cohorts of students taking the Fundamentals of Database Systems module: a

full-time face-to-face cohort consisting of 920 students, a part-time face-to-face cohort consisting of 177 students and a fully online part-time cohort (no face-to-face contact) consisting of 14 students. Using the experimental design criteria identified by Joy and Garcia (2000), the prior knowledge and ability of the students in the three cohorts were similar, the instructor effects were minimal and the time on task was the same for each cohort. In the interests of impartiality, exams were blind marked and because of large class sizes, courseworks were marked by a number of staff with no prior knowledge of the students. Only the online students were given access to the games-based learning environment. To determine whether there was any observable difference between the three cohorts, we used the University's grading system. Figure 3 shows the module percentage by module and mode of attendance. A Chi-squared test using the crosstab frequencies was performed. This test can be seen in one of two ways: it is either a test for independence between mode of attendance and grade or that each mode of attendance gives the same profile across grades. In Figure 3 the percentage in each grade is shown with the corresponding result for the test. It is noted that a highly significant result is detected.

	A	B1	B2	C	D	E	χ^2 test
full-time	24.4	22.3	20.7	16.0	9.0	7.7	p<0.001
part-time	31.5	22.8	16.8	14.1	4.0	10.7	
online	26.7	33.3	6.7	26.7	0.0	6.7	

Figure 3: Chi-squared test for independence of mode of attendance and grade

As reported in some other studies (e.g. Carr, 2000; Ditton et al., 2002) an online delivery can have high dropout rates. An analysis of dropout rates showed that the face-to-face students had a 13% dropout rate whereas the online students had a 7% dropout rate (representing one student who dropped out). We also examined both student and faculty perceptions the online environment. Both groups provided extremely positive comments, although on the negative side faculty were concerned that the development costs of the online environment were high and that, while cohort sizes were small workload would be similar, scalability would be an issue and larger online cohort sizes would require a significantly higher workload than teaching a comparable number of face-to-face students.

6. Summary and future directions

This paper has discussed some of the pedagogical issues underpinning the development of a constructivist learning environment using problem-based learning and a simulation game and inter-

active visualizations to help teach database analysis and design.

Future work will include completion of the development of level 3 of this environment and evaluation of the appropriateness of this environment for different groups of students (undergraduate and postgraduate, full-time and part-time). The evaluation will include both quantitative and qualitative measures to examine the effectiveness of the environment, looking not just at any perceived grade improvements but also at any perceived levels of improved satisfaction from student and instructor perspectives (Joy and Garcia, 2000; Hiltz et al., 2000). The current aim is for the game to maintain a journal of student interaction that will aid this

evaluation and provide a source of information for further reflection. Additional work will be necessary to consider the applicability of this environment to online students, particularly the collaboration element of the activities.

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